

Teaching about energy

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1 Introduction

Energy is an important idea in all branches of science, so you probably feel familiar with it whether your background is in physics, chemistry or biology. You may think of energy as an idea that you understand, which should not therefore be too difficult to teach.

In fact it is much less straightforward than it appears, for two main reasons:

1. In science, energy is an abstract, mathematical idea. It is hard to define ‘energy’ or even to explain clearly what we mean by the word.
2. The word ‘energy’ is widely used in everyday contexts, including many which appear ‘scientific’ – but with a meaning which is less precise than its scientific meaning, and differs from it in certain respects.

The first means that, in order to communicate the scientific idea of energy to young learners, we have to simplify it – but still ensure that what we teach is clear and useful, and provides a sound basis for developing a fuller understanding later. The second means that we have to be very careful to disentangle the everyday usage of the word ‘energy’ from its scientific use, in order both to keep our own ideas clear and to avoid teaching pupils a potentially confusing mixture of the two.

2 Arguments and debates about the teaching of energy

Because of the two points above – particularly the first – there has been a long and often heated debate about how energy should be taught in lower secondary school. Since the Nuffield O-level Projects in the 1960s, it has been common to introduce ideas about energy in a non-mathematical way, in lower secondary school science courses. Some aspects of this approach, however, have been severely criticised – as inaccurate, or misleading, or an obstacle to later learning. This is discussed more fully in section 6 below. Some of the points made in this debate influenced the wording of the first Science National Curriculum in 1989, and have continued to influence later versions. The reason for the National Curriculum’s choice of wording, however, has not been fully grasped by some textbook authors, or some writers of examination questions – who have tried to implement the ‘official’ approach but without sufficient understanding of it. The result is that many textbooks at this level have energy chapters that are confused and confusing. Some contain incorrect (as opposed to merely simplified) explanations and definitions of terms. There is also quite wide variation in the terms used in different texts. Also many energy questions, including some in public examinations, are worded in obscure and unclear ways, and reward the ability to use taught conventions which are not themselves scientifically accurate, rather than probing genuine understanding of energy ideas.

It is not an overstatement to say that the teaching of energy is in a mess. Improving the situation is a long-term project. The starting point is to ensure that as many science teachers as possible have a clear understanding of the scientific energy concept, and are aware of the issues about energy teaching that have been discussed and debated – so that they can teach about energy in as clear and accurate a manner as the current curriculum, textbooks and examining system allow them to, and can gradually help to influence these to change for the better.

3 Overview of this paper

A starting point for thinking about how to teach energy is to clarify your own understanding. So the next section (section 4) looks at the scientific idea of energy. Following that, section 5 considers how the word ‘energy’ is used in everyday contexts, how this differs from the scientific use of the term, and the possible implications of this. Section 6 then outlines and discusses some of the main issues that have been raised about energy teaching. Having outlined the issues and difficulties, the remainder of these notes suggests how we might go about the teaching of energy, avoiding the worst pitfalls. Sections 7 and 8 proposes a teaching sequence, starting with ideas about energy resources and leading on to looking at processes and events in energy terms. The final two sections then discuss briefly some issues concerning the ideas of chemical energy and heat.

4 The scientific idea of energy

The Nobel Prize winning physicist, Richard Feynman, begins his discussion of the scientific idea of energy as follows:

There is a fact, or if you wish a law, governing all natural phenomena that are known to date. There is no exception to this law – it is exact so far as is known. The law is called the conservation of energy. It says that there is a certain quantity, which we call energy, that does not change in the manifold changes which nature undergoes. That is a most abstract idea, because it is a mathematical principle; it says that there is a numerical quantity, which does not change when something happens. It is not a description of a mechanism, or anything concrete; it is just a strange fact that we can calculate some number and when we finish watching nature go through her tricks and calculate the number again, it is the same. (Feynman, 1963, p. 4-1)

There are several important points to note here. First, the most important idea about energy is that it is conserved – in every event and process, there is the same total amount at the end as there was at the beginning. It is this that makes energy a useful quantity. It is not too strong to say that if energy was not conserved, it would not exist as a scientific concept.

Feynman also emphasises that energy is an abstract, mathematical idea. It is a property of an object or system¹, which can be given a numerical value. It is not concrete ‘stuff’. That means that we should talk about the energy of an object or system, but not about the energy in (or contained in, or stored in) it.² However, I will argue later (in sections 6.1, 7 and 8) that talking about energy as though it were a kind of quasi-material substance that can be transferred from one place to another is almost unavoidable – and that this is a ‘good enough’ model to use when introducing the idea of energy to 11-14 year olds, which will not form a serious barrier to later learning.

Finally, Feynman points out that energy is not a mechanism that explains how things happen. It does not help us to understand how or why they happen. When we introduce pupils to energy ideas, we are not providing them with an idea which is of immediate practical use. Instead we are introducing them to a very general, overarching point of view that can be used to think about an enormously wide range of phenomena, across all the sciences. Energy provides an integrating framework. It can be intellectually

¹ A ‘system’ just means a group of objects that can be treated as a single unit.

² In much the same way, we would talk about the mass of something, but would not talk about the mass contained in it. Mass is a property of the thing. So is energy.

satisfying to see diverse events from a single unifying perspective. It is a ‘neat idea’, rather than a practically useful one. Later, of course, it can become very useful, for anyone who pursues science further. But it only really comes into its own when we can treat the ideas mathematically, and calculate amounts of energy in different situations.

Feynman describes energy as ‘a numerical quantity, which does not change when something happens’. But he does not attempt to say what this numerical quantity measures. As several numerical quantities do not change when an event occurs (for example, the total mass, the total electric charge, the total momentum, and some others), it is necessary to say something, however imperfect, about what the numerical quantity we call ‘energy’ measures. Energy is a measure of the amount of work an object or system is capable of doing, under ideal conditions. ‘Work’ is, itself, a precisely defined scientific term (the product of a force and the distance moved along its line of action). But even if we think of ‘work’ in a looser, everyday sense, this definition of energy makes sense: when we have a lot of energy, we feel capable of doing lots of work; when we have little energy, we are incapable of doing much work. Energy is a measure of the capacity of an object or system to do work.³

5 ‘Energy’ in everyday contexts

The earliest use of the word ‘energy’ (according to the Shorter Oxford English Dictionary) was around 1600, when it meant ‘force or vigour of expression’ – much the same sense as when we describe someone (or ourselves) as ‘energetic’, or ‘full of energy’. The word was then adopted and used by scientists working during the period from 1780-1850 to develop a formal mathematical theory of processes involving heating and motion (now known as thermodynamics) as the name of a particular property of an object or system – its capacity to do work. Since then, however, the term ‘energy’ has remained in everyday use, with both its original pre-scientific meaning, and also with some additional meanings that draw on the scientific idea but are not as precise or careful.

For example, in everyday discourse, energy is something we ‘use’ and ‘consume’. Phrases like ‘energy use’ and ‘energy consumption’ are common. We buy energy from the ‘energy utilities’, companies that sell us gas, oil or electricity, to use in our homes. Advice from electricity and gas supply companies tells householders how to reduce their energy usage, by insulating their homes or changing to more efficient devices, like more modern central heating boilers or energy-saving light bulbs. Government statistics published annually tell us about ‘energy consumption’ in different sectors of the economy, such as industry, transport, domestic, and so on. Certain foods are said to give you a lot of energy, or to provide a quick energy boost when you need it. In this way of talking – which is not scientific though it is influenced by scientific ideas – energy is a commodity or a resource. We buy it and use it. It comes in different forms, such as petrol, oil, gas, coal (and food).

This way of talking, however, can blur the distinction between the scientific and everyday meanings of ‘energy’. We all become used to talking about energy in ways that are not completely scientific – and, as a result, can come to think of energy in

³ Some people feel uncertain about this definition because they know (from the Second Law of Thermodynamics) that it is impossible to use all the energy of a hot object to do work. But this restriction applies only to what is possible in a cyclic process.

ways that are not in line with the scientific idea. This then poses problems for how we teach about energy, when we need to avoid the looser criteria that apply to everyday discourse about ‘energy’, and use words and ideas more precisely and carefully.

6 Arguments and debates about teaching energy

The Science National Curriculum includes ideas about energy resources and also ideas that relate to the scientific energy concept, such as conservation of energy. A common way to develop these ideas, reflected in textbooks and in questions in national tests and GCSE papers, is to get pupils to think about events and processes in terms of energy transfers from place to place, or energy transformations from one ‘form’ to another. Some aspects of this approach have, however, been severely criticised, and there has been much debate about how best to talk about energy ideas.

6.1 Abstract property or invisible ‘stuff’?

An outspoken critic of the way energy has been taught since the Nuffield curriculum projects of the 1960s is John Warren. Warren (1982) insists that energy is an abstract mathematical concept, and argues that teaching must start from its scientific definition or else all that is taught is confused and largely meaningless. This definition (see section 4 above), however, requires that you already understand the scientific idea of work, which in turn depends on understanding force. For most teachers (and pupils), this approach is too abstract and formal. Warren accepts that it is only suitable for older students; in one article he writes:

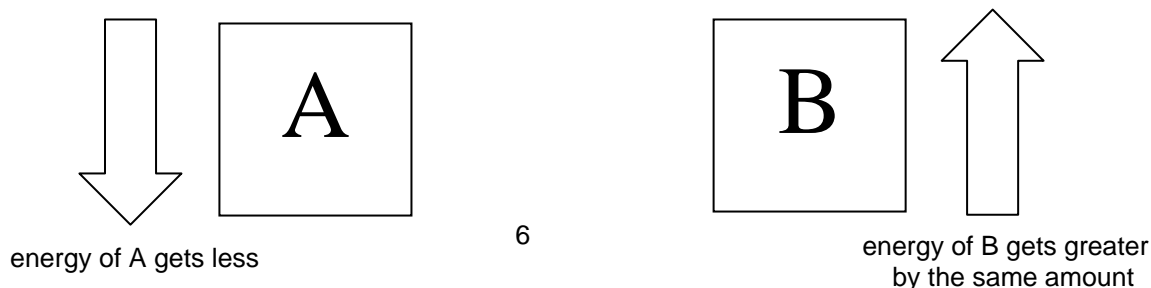
There are just two ideas about energy that can, and should, be taught to all pupils below the sixth form:

- (1) Energy is the name of an important bit of mathematics that you will learn about if you ever study science or engineering at advanced level.
- (2) A lot of people who do not know anything about it use the word ‘energy’ to mean all sorts of different things, most of which are silly. Take no notice of them. (Warren, 1991:8-9)

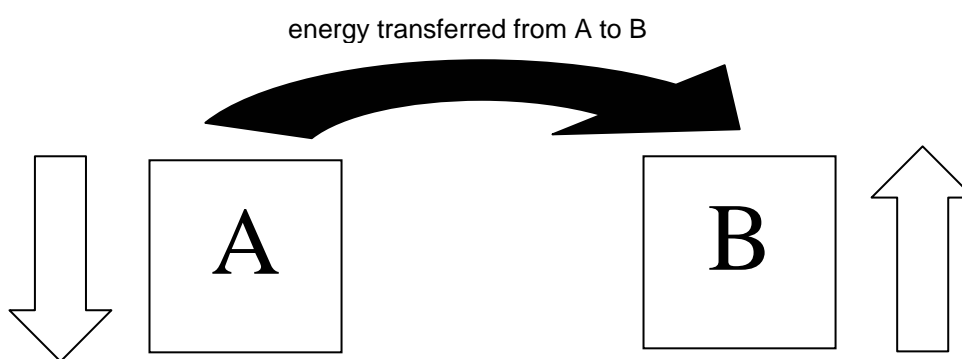
But there are some things about energy (in particular about energy resources) that every citizen ought to know – and making energy a topic only taught to the few who continue their study of science into the sixth form is not an acceptable solution.

For Warren, the fundamental flaw in a qualitative treatment of energy is that it makes energy appear to be a ‘magic substance’, invisible and intangible, but able to flow from place to place, changing its form as it goes, whilst staying constant in quantity. Others, however, see this as an acceptable, indeed a valuable, way of simplifying a difficult idea (for a discussion, see Duit, 1987).

In fact, it is hard not to think of energy as ‘something’ that flows, or is somehow transferred, from place to place – rather than just thinking of it as a number that does not refer to anything ‘real’. Imagine two objects, A and B, that interact in a process of some kind. The energy of A decreases – and the energy of B increases by the same amount.



It is easy to see this as meaning that something (energy) has been transferred from A to B.



So we develop a model of energy as a kind of intangible substance that flows from place to place, as a way of making sense of energy conservation. This is, however, a model – which is not exactly in line with the scientific idea of energy – and it is helpful to keep this in mind as you use it. If we use this model carefully it can be a valuable tool for developing understanding. However, treating energy as a quasi-material substance can also lead to problems and difficulties, some of which are discussed in sections 6.2 and 8.3 below.

6.2 *Transfer or transform?*

When we use a model of energy as something that can be stored in different places (and ways) and can flow from place to place, it is tempting then to label the different ‘forms’ that energy can take. Many textbooks and teaching schemes do this. In a typical Key Stage 3 level textbook, these might be: kinetic, potential (perhaps split into gravitational potential and elastic potential), heat (or thermal), chemical, electrical, light.

This ‘forms of energy’ approach has, however, been the subject of much debate. One criticism is that pupils just learn a set of labels, which adds little to their understanding. For example, one current textbook uses the example of a battery-powered golf buggy. It asks pupils to think of this in the following terms:

Chemical energy in the battery is transformed into electrical energy which is carried by the wires to the motor. The motor then transforms this into kinetic energy as the buggy moves.

This, however, adds nothing to the following explanation, which does not use energy ideas:

The battery supplies an electric current which makes the motor turn. This then makes the buggy move.

A good general rule when explaining anything is that you should use the smallest

number of ideas needed to provide an explanation, and not introduce any that are unnecessary⁴. The explanation above using energy ideas fails this test. The same applies to many descriptions of devices as ‘energy converters’. Saying that a light bulb ‘transforms electrical energy into light energy’ adds nothing to the simpler (and more scientifically accurate) statement that it ‘emits light when there is an electric current through it’.

The forms of energy approach can also lead to analyses of situations which introduce unnecessary variables that do not contribute to understanding. For example, several textbooks discuss the energy changes when a person lifts an object up to a height, describing this as chemical energy (in the person’s muscles) changing into kinetic energy (of the object as it moves upwards) which is finally stored again as gravitational potential energy. The intermediate stage here – the kinetic energy of the moving object – is not a useful quantity to know about. The amount of kinetic energy tells us nothing useful about the overall process. Indeed it will depend on the speed at which the object is raised. But the amount of potential energy which the object gains (and, to a reasonable approximation, the amount of chemical energy lost by the lifter’s muscles) are the same, whatever the speed. An energy analysis that includes kinetic energy as one stage is simply introducing complexities that are irrelevant. In fact a much more useful analysis would be to note that some of the chemical energy that is lost appears as thermal energy (in the lifter’s muscles which rise in temperature), as well as the portion that appears in increased gravitational potential energy of the object lifted – again focusing on the initial and final states rather than intermediate ones. Another example of an analysis that introduces unnecessary and unhelpful intermediate stages is discussed in section 8.4.

In some situations, the forms of energy approach can lead to incorrect analyses of processes. For example, one currently popular textbook includes a diagram showing energy transfers in a moving car. It shows stored energy in the petrol being transferred to the car (as movement energy) and to parts of the car and the surrounding air (as heat). This is an acceptable analysis for the period when the car is speeding up, and might seem plausible at first sight for a car travelling at a steady speed. But if a car is going at a steady speed, the amount of petrol (and hence of stored energy) in its tank is decreasing all the time, yet its speed (and hence its kinetic energy) is staying the same. A more correct energy analysis of a car moving at steady speed would show all of the energy stored in the petrol ending up in the hotter parts of the car and its surroundings.

Another criticism of the ‘forms of energy’ approach is that it focuses attention in the wrong place, on the ‘form’ of the energy at different points, rather than on the processes by which energy is transferred from one object or system to another. Ellse (1988) argues that the latter is simpler, more useful and more important. He proposes that we should not use any labels for forms of energy and just talk about ‘energy’ being ‘transferred’ from place to place, rather than ‘transformed’ or ‘converted’ from one form to another. Whilst this works well for some processes, however, it works less well with others. For example, consider the simple situation of an object falling from a height or sliding down a smooth slope. Here we are interested in the energy of the same

⁴ This principle is sometimes called Occam’s razor, after the mediaeval philosopher who first stated it.

object at the beginning and end⁵ – and it seems clearer to talk about its potential energy having been transformed (or converted) into kinetic energy than to try to explain it using only the word ‘transfer’. Similarly, if we think of two similarly charged objects that are held close together and then released, the easiest way to talk about this in energy terms is as a transformation of potential into kinetic energy. To talk clearly about events in energy terms, we need both the terms ‘transfer’ and ‘transform’.

The National Curriculum largely avoids ‘forms of energy’ language, and talks of energy being transferred rather than transformed. Many textbooks and examination questions, however, have tried to retain some of the ‘forms of energy’ language but to avoid the word ‘transform’. They then talk about energy being transferred from one form to another (e.g. ‘transferred from chemical energy in a person’s muscles to kinetic energy of something that they move’). This just doesn’t make sense – and certainly doesn’t make for clear communication. The way to avoid this is always to use transfer to mean from place to place.

Ellse (1988) also argues that it is misleading to use the term ‘electrical energy’ to talk about what is happening in an electric circuit⁶. Energy is a property of an object or system – but in a simple electric circuit there is no object or system that has a measurable (or even definable) amount of ‘electrical energy’⁷. In simple circuits, an electric current is a means of transferring energy from one place to another – from the battery to another component in the circuit, and perhaps on into the environment. Rather than thinking about amounts of energy in different places or forms, the more useful and interesting quantity is the rate at which the energy transfer is taking place. For this reason, it helps us think more clearly about these processes if we talk (and think) about ‘energy being transferred by an electric current’ or ‘energy being transferred electrically’, rather than ‘electrical energy’ – that is, as a way in which energy can be transferred rather than as a ‘form’ in which it can be stored.

For similar reasons, ‘light energy’ can also cause problems. In most situations, we are more interested in the rate at which energy is being transferred from one place to another by light (or by any other kind of radiation) than in the amount of energy stored. If we drew an imaginary boundary around a region in which there was light, then we could, in principle, calculate the amount of energy it contained – each light photon has a certain amount of energy, and we could multiply this by the number of photons present. But this is rarely useful – and the number we got would depend on the size of the region we considered. In most situations, it is more useful to think of light as a way in which energy can be transferred from one place to another.

6.3 *Energy is not a cause*

It is common to talk about energy as though it were the cause of events. Energy is what makes things happen, or makes them ‘go’. For example Key Stage 3 textbooks say things like:

Energy is needed to get jobs done, or to make things work.

⁵ Strictly speaking, gravitational potential energy is not the energy of the object alone, but of the object in the field, i.e., of the object-Earth system.

⁶ He notes, though, that it is reasonable to talk about ‘electrical energy’ in other situations, such as in a charged capacitor, or any arrangement in which attracting electric charges have been separated.

⁷ Whilst this is true for all the circuits we would want to discuss at Key Stage 3 or 4, a circuit which has appreciable inductance or capacitance can store energy – and it would not be unreasonable to call this ‘electrical energy’. However this is not what is meant by ‘electrical energy’ in most textbooks that use the term.

*Without energy nothing can ever happen.
You need energy to move and to work.*

Ogborn (1986), however, points out that it is incorrect to say that ‘energy is what makes things happen’, or that something happens because of energy. So statements like the following are incorrect:

*A ball keeps moving because it has kinetic energy.
Petrol makes a car go because petrol has energy.
A stone falls because it has potential energy.*

One reason for avoiding causal statements like these is that energy is not a mechanism. We need to use other ideas (like force) to explain how and why things happen. Looking at an event from an energy point of view might throw light on some aspects of it – but does not help to explain how or why it happens. A second reason is that energy is conserved. So it cannot explain why the process runs in one direction rather than the reverse (which would also conserve energy).

From a scientific point of view, it is *entropy* (or *free energy*), rather than energy, that can be said to ‘make things happen’. In any spontaneous event, entropy increases ($\Delta S > 0$) (and free energy decreases ($\Delta G < 0$)). These ideas, however, are generally thought to be too abstract and difficult to introduce at school level, though we hint at them when we use ideas like ‘energy spreading’ or going from a ‘concentrated’ energy store to more ‘dispersed’ ones. So, whilst it is strictly incorrect to say that ‘energy makes things happen’, in an introductory course it is reasonable enough to say that an energy store of some kind is necessary for something to happen.

Searching for a simpler language to introduce these ideas to young learners, Ogborn (1990) suggests using the idea of *difference* to explain why things happen. Differences in temperature, concentration, shape (of a springy object), position in a field, or location (i.e. motion) can cause something to happen. When it does, the differences get less. Spontaneous events never result in greater differences. If they appear to, it is always at the expense of a reduction of difference somewhere else. Ogborn and Boohan have developed these ideas into an interesting and novel teaching approach which is explained fully in three booklets (Boohan and Ogborn, 1996a), and more briefly in a journal article (Boohan and Ogborn, 1996b). Although the approach has not caught on in schools to any great extent, these materials contain ideas that you may find useful, both to stimulate your own thinking about energy and to suggest activities that you might incorporate in your teaching.

7 Teaching energy ideas

The previous two sections of these notes have raised several issues about energy teaching, and outlined some of the debates about it. So what should we do? This section and the next suggest a way of teaching about energy which takes account of the issues that have been raised, introduces pupils to important ideas about energy, and provides a sound basis for further learning.

A good place to begin the teaching of energy ideas is with energy resources, (including food). There are ideas about energy resources and the way we use them that are important for all citizens – and which all young people should be taught. We

all have choices to make about our personal use of energy resources, and our views (for instance on how high the tax should be on petrol and diesel, or on the methods we should use to generate electricity) can influence national policy. As far as possible, these choices and decisions should be made on an informed basis.

Most pupils in Year 7 will know the word ‘energy’ from everyday discourse, and many will associate it with fuels and food.⁸ Indeed, rather than emphasising the word ‘energy’, there are some advantages in focusing on the word ‘fuel’. We want to avoid talking about ‘energy use’ and ‘energy consumption’, as this might cause problems later, when we want to introduce the idea that energy is conserved. We can talk, however, about ‘fuel use’ and ‘fuel consumption’ without any inaccuracy. If you do use the word ‘energy’, it is better to talk about ‘using (or consuming) energy resources’ rather than about ‘using (or consuming) energy’.

The idea that most jobs need a fuel of some sort is likely to seem reasonable. A useful introductory activity, which dates back to the original Nuffield courses, is to get pupils to divide a given list into ‘things that need a fuel’ and ‘things that do not need a fuel’. (For example, a shelf holding up a row of books is an example of something that does not need a fuel.) You can then go on from this to talk about things like:

- the range of fuels we use in everyday life;
- the amounts used in different areas of life (homes, at work, transport, etc.);
- how the total amounts used have changed over time;
- the differences in amount (and type) of fuel used in different regions of the world and the consequences of this.

All of these are important things for citizens to know about.

In discussing the range of fuels we use every day, electricity is almost certain to be mentioned. At this level, it is acceptable to call electricity a fuel, pointing out that it is a ‘secondary’ fuel, which has to be generated using a ‘primary’ fuel (such as gas, or oil or coal). An important issue to discuss is the limited amount of fossil fuels available, the relatively short period of time for which we have been using them and the increasing rate at which we are doing so, and the need therefore to use them carefully – perhaps mentioning concerns about the side effect of carbon dioxide production and its possible link with global warming.

This might lead on naturally to a discussion of renewable energy sources, such as wind, sunlight and waves. It does not seem very natural to call wind, sunlight and waves ‘fuels’, or ‘energy resources’. Calling them ‘energy sources’, or simply talking about ‘wind energy’ and ‘solar energy’, seems more natural – and unlikely to cause many problems of understanding – even though you have not defined exactly what ‘energy’ means.

The idea that foods (or certain foods) are the ‘fuel’ for living organisms can also be introduced here, as the basic idea is similar. Indeed activities based on energy information (in joules) on food packaging can be a good way of introducing the idea that amounts of energy can be measured – though at this stage it would not be wise (nor is there any need) to try to explain how this can be done or what the units mean.

⁸ For a summary of the main findings of research on pupils’ ideas about energy, see Driver et al., 1994.

Discussing the topics above also brings in (or can bring in) other ideas that are valuable for every citizen to know something about. It is useful, for instance, to know that some of the appliances we use at home use fuel much more quickly than others – that an electric heater, for instance, uses fuel much faster than a light bulb or a radio. The idea of ‘efficiency’ is also important. It takes less fuel to heat water, or to keep it hot, in a well-insulated tank than an uninsulated one. An efficient central heating boiler uses less fuel to heat the water – because it wastes less heating the air. Compact fluorescent light bulbs are preferable to filament bulbs, because they produce the same amount of light for less fuel (back at the power station). Notice that all of these can be explained quite clearly using the word ‘fuel’ and without mentioning the word ‘energy’.

In the course of teaching these ideas, you are quite likely to find yourself talking about fuels as ‘energy sources’ and implying that energy can be stored in certain places and transferred to other places as a process proceeds. This is treating energy as a quasi-material substance – which is not strictly correct. However, it is almost impossible to talk simply about energy without using this idea – and several authors have argued that it is not a serious hindrance to the later development of a more precise scientific understanding of energy (Duit, 1987; Kaper and Goedhart, 2002a, b).

8 Thinking about events in energy terms

The next stage is to help pupils begin to think about events and processes in energy terms. Here again, we will use a model of energy as a quasi-material substance that can be stored in different places (and in different ways) and can be transferred from one object or system to another. However it is important to take some care about exactly how you do this, and the terms you introduce and use. In the approach suggested below, energy ideas are introduced qualitatively, but in a way that leads easily to a more quantitative understanding at a later stage.

8.1 *Where is energy stored at beginning and end?*

A good starting point is to take some simple processes that can easily be described or demonstrated in the lab, and ask pupils:

- what has got less energy at the end of this process than it had at the start?
- and what has got more energy at the end of this process than it had at the start?

For reasons that are discussed later, it is better to ignore the stages in between and just to concentrate on where energy is stored at the beginning and the end.

In order to answer these questions, pupils have to know how to ‘spot an energy store’. So, in discussion, you need to build up a list of ways in which we can recognise an energy store:

- some chemicals (or combinations of chemicals⁹) have energy (chemical energy)
- something that is hot has energy (thermal energy)¹⁰
- something that is moving has energy (kinetic energy)

⁹ This point is discussed more fully in section 9.

¹⁰ You may prefer to call this ‘heat’ even though this is not strictly correct (see section 10 later). This also assumes that pupils already have some understanding of the difference between heat and temperature.

- something elastic that is squeezed or stretched has energy (elastic potential energy)
- something that has been moved from its ‘natural position’ in a field has energy (e.g. lifted up in a gravitational field, two unlike charges moved apart, two attracting magnets moved apart) (field potential energy).

It is not essential to use the ‘forms of energy’ labels in brackets after each item in the list above, but they may be useful shorthands for referring to each of the ways in which energy can be stored.

Good examples to use for this activity are ones where the initial energy store, and the places where energy is stored at the end, are reasonably easy to spot. For example:

1. a camping gas stove heating water in a saucepan
2. a battery connected to a resistor coil, heating water in a beaker
3. a battery connected to a motor, raising a load
4. a block fired across the floor using an elastic band catapult
5. a ball (or small vehicle) released at the top of a ramp and rolling down

The first involves a fuel, which most pupils will accept as an ‘energy store’¹¹. There is less gas in the stove at the end (and hence less energy stored in it). Extending this to the chemicals in the battery (examples 2 and 3) is also not too difficult. Example 4 requires pupils to see the stretched elastic as another kind of ‘energy store’. Example 5 brings in the idea that energy is also stored in something that has been raised up to a height.

Note that ‘electrical energy’ and ‘light energy’ are not included in the above list of ways that energy can be stored. The reason (as discussed earlier) is that it is rarely useful to think of energy as being stored in the form of electricity or light. These are better thought of as ways in which energy can be transferred from one place to another.

To develop these ideas:

- You might draw attention to the fact that the final store for energy in many processes is the environment, which gets a little bit hotter. (For example, it can be useful to consider two different ‘ends’ of the process in example 4 above: (i) just as the block leaves the catapult; (ii) when it has eventually come to rest.)
- You might note that often the energy starts in a single store but ends up in several different stores, one or more of which involves something getting hotter.
- You might discuss examples like a battery lighting a bulb. Rather than think of light as the final energy store, it is better to think the process through to the end – and regard the objects that absorb the light, and get slightly warmer as a result, as the final energy store.
- You might introduce examples involving mains electricity. Here the initial energy store is not electricity or ‘electrical energy’ – it is the fuel used in the power station to generate the electricity.

As well as identifying different ways in which energy can be stored, we can identify several different ways in which energy can be transferred from one store to another:

- mechanically (by a force pushing or pulling something);

¹¹ In fact it would be more accurate to say that the combination of (fuel+oxygen) is the energy store. Both are needed to enable anything to happen. This is discussed more fully in section 9.

- electrically (by an electric current);
- by heating (due a temperature difference¹²);
- by radiation (both electromagnetic and mechanical (e.g. sound)).

Energy is also transferred in a chemical reaction from the reagents to the products, but there is no simple word to describe this way in which energy is transferred. The first two can be formalised later as *mechanical work*, and *electrical work*, both of which can be precisely defined, and measured.

Some devices can be thought of as changing the way in which energy is being transferred, without actually storing any themselves. For example, we can think of a motor as having energy transferred to it electrically, and from it mechanically.

8.2 *Conservation of energy*

As Feynman highlights in the passage quoted in section 4 above, the most important fact about energy is that it is conserved. The conservation of energy is one of the fundamental principles of science. So in talking about processes and events in energy terms, we do not only want to describe where the energy is stored and how it is transferred. We also want to tell pupils that, in any event of process, the amount of energy lost by the store is equal to the sum of the amounts of energy gained by the various reservoirs. Energy is a kind of book-keeping quantity. The ‘energy books’ must balance at the beginning and the end. It should always tally.

We have, of course, no way of demonstrating to pupils that energy is conserved, as we do not, at this stage, have any way of measuring amounts of energy. It just has to be asserted. But it is necessary to say something more about it, in order to make it seem plausible – as most people’s intuition is that something is used up in all events and processes, and not that something is conserved.

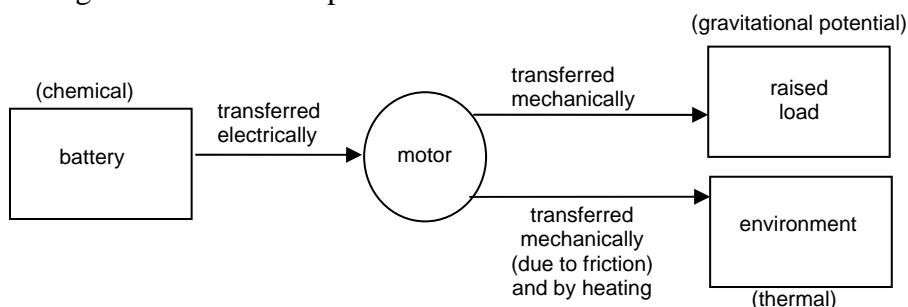
Also, if energy is conserved, and there is always the same amount of energy at the end of a process as there was at the beginning, why do we need to ‘save energy’? These may appear to pupils to be contradictory viewpoints. You cannot just gloss over this. The issue needs to be openly discussed, and the apparent contradiction resolved. The best solution is to introduce the idea of energy *dissipation at the same time* as the idea of energy *conservation* (Solomon, 1982; Ross, 1988). So although the total amount of energy is always the same after a process as it was at the start, it is now more spread out, and less useful for doing things with in future. It is concentrated stores of energy, such as fossil fuels, that are valuable and need to be ‘saved’, or conserved.

8.3 *Representing events and processes in energy terms*

The set of ideas above gives us a way of talking about events and processes clearly and consistently in energy terms. The ways of storing energy and ways of transferring energy used have been chosen so as to make the transition later to a more quantitative treatment as easy as possible.

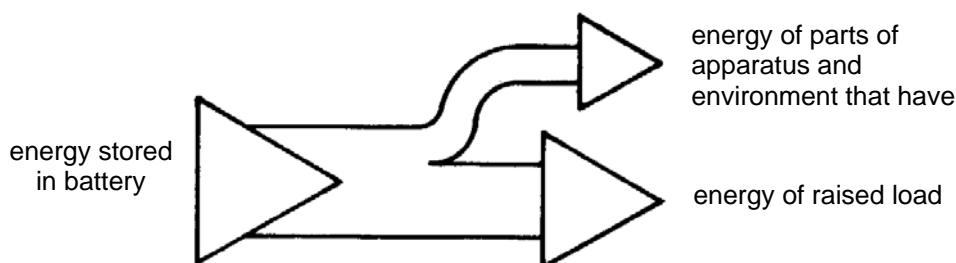
¹² Note that this implies that pupils understand the difference between temperature and heat (or thermal energy) before they start on this. Strictly ‘heat’ is not the same thing as ‘thermal energy’ but at Key Stage 3 it would be a mistake to make too much of this. The important thing is that pupils can distinguish ‘heat’ and ‘temperature’, and use the two ideas correctly.

A useful learning activity at this stage is to get pupils to represent some given events or processes diagrammatically, in energy terms. For example, a battery connected to a motor, raising a load could be represented as follows:



Here the rectangles show the initial and final energy stores – and the circle shows a device which changes the way in which energy is being transferred.

Another way of representing the same process is to use a Sankey diagram:



The first diagram has the advantage of showing how the energy is being transferred at different stages in the process. The second is better for showing the relative amounts of energy that end up in different places – which can be useful when discussing efficiency, for instance. Another advantage of Sankey diagrams is that the width of the arrows communicates visually the idea that energy is conserved – the total amount of energy is the same at beginning and end. It is a good idea to use both, as each captures a different aspect of the event.

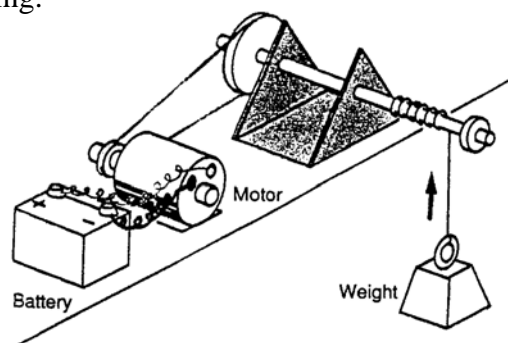
A very useful pupil activity at this stage is to have pupils, either individually or in small groups, consider several examples of events and processes, drawing diagrammatic representations of them, using both of the types of diagram above. They will first need to be talked through several examples, to get the idea of the conventions to be used. The ability then to apply this to other examples is a good indicator that a pupil has grasped the key ideas and is beginning to be able to think of events and processes in energy terms.

8.4 Choosing examples

It is important to take care in the examples you choose for the kind of activity described above. Good examples are ones where the initial energy store and the final energy store(s) are clear. You should also make clear exactly which instants you are regarding as the start and the end of the event.

Focus on where the energy is stored at the beginning and the end of the event, and don't worry too much about where it is in the middle – as this is rarely useful and can often be positively unhelpful and misleading.

For example, consider a battery running a motor which turns a pulley (via a belt) and raises a weight.



Many textbooks represent this in energy terms, along the following lines:

chemical energy → electrical energy → kinetic energy → grav. potential energy + thermal energy
 (in battery) (in wires) (in moving parts of motor and belt) (in load) (in motor, pulley)

Some parts of this, however, are problematic. The problem with electrical energy has already been noted: energy is a property of an object or system; so what is the object or system that has this electrical energy, and how much does it have? There isn't one, and the amount could not be calculated. The rate at which energy is being transferred electrically is a much more useful quantity to consider.

The kinetic energy stage is also problematic. We certainly could identify objects that are moving, and therefore have kinetic energy. But the amount of kinetic energy they have is irrelevant to an understanding of the overall process. If we replaced the belt by a lighter one, but of the same strength, it would have less kinetic energy – but the process would continue as before. The kinetic energy of the moving parts is not a useful quantity to know. There is no need to bother about it.¹³

It would be better to forget about these intermediate stages – remembering that energy is not a description of any mechanism – and focus on the initial and final energy stores. Then the process would be represented in energy terms as:

chemical energy → gravitational potential energy + thermal energy
 (in battery) (in load) (in motor, pulley, etc.)

It is also wise to avoid situations that involve something being maintained at a constant speed, for example, a car travelling at steady speed or an electric drill or food-mixer (at least, until pupils can deal confidently with easier ones). In examples like these, the most obvious outcome is motion, so pupils are likely to see them in terms of energy transfer from an initial store to the kinetic energy of the moving object, perhaps with some being wasted to heat parts of the device and its environment. This analysis is reasonable for the period in which the moving object is speeding up. But while it is running steadily, the amount of kinetic energy it has

¹³ The same argument was used earlier when discussing the 'lifting an object' example in section 6.2.

remains unchanged. So all of the chemical energy in the initial energy store is being transferred to parts of the device and their environment, heating them up¹⁴. This is not obvious, so these are not good examples of energy transfer to use to introduce these ideas.

9 Sorting out ideas about chemical energy

It is difficult to teach about fuels (including food) as energy resources without saying, or at least implying, that these ‘contain energy’, or are ‘energy sources’, or ‘energy stores’. It is more accurate, however, to think of the energy as being stored in a combination of chemical substances, rather than in one. A hydrocarbon fuel on its own can do nothing. It needs oxygen. The fuel is one part of a fuel-oxygen system. Energy is released when the hydrocarbon reacts with oxygen. We might just as well call oxygen the fuel – and say that it needs a hydrocarbon to release its energy.

Ross (1993) discusses the misconceptions that can arise if we imply that fuels ‘contain energy’, and argues for a fuller explanation that draws attention to the role of oxygen. One widespread misconception is that energy is stored in the bonds of substances, and released when these bonds are broken – rather like a fluid leaking out of a broken pipe. In fact energy has to be supplied to break bonds, rather than released when they break.

When methane (a fuel) reacts with oxygen, the first stage is for the bonds in some methane and oxygen molecules to be broken. Some energy is needed to do this, e.g. from a match. The fragments then recombine, to form molecules of carbon dioxide and water vapour. This is rather like two unlike charges coming together, and releases energy – which is stored as thermal energy in the products of the reaction (hot carbon dioxide and water vapour). Because of the strengths of the various bonds involved, less energy is required to break the methane and oxygen molecules apart than is released again when the fragments recombine to form carbon dioxide and water. So once the reaction is triggered (by a match), it will then run continually as long as both methane and oxygen are present.

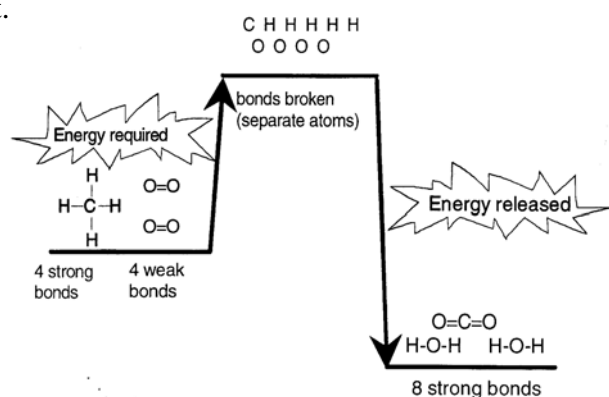


Diagram from
Ross (1993)

10 Sorting out ideas about heat

These notes have not made much use of the word ‘heat’ but have talked instead of ‘heating’ as one of the ways in which energy can be transferred from one object to another. The label suggested for the energy stored in a hot object was ‘thermal energy’.

¹⁴ You could think of kinetic energy being continually supplied to the moving object at the same rate as it is being transformed to thermal energy by the friction forces present – but it is simpler just to think in terms of the beginning and end states..

'Heat' is also a term that is used in everyday language in a way that is different from its scientific meaning, and much less precise. Several articles have been published pointing out some common misconceptions about heat, and inaccuracies in the way the word is used in teaching (Warren, 1972, 1976; Ogborn, 1976; Mak and Young, 1987). Some have suggested that the noun 'heat' should be dropped, and that we should refer instead to the process of 'heating' (Heath, 1974, 1976; Summers, 1987). The latter has not caught on, but the argument may have encouraged some people to avoid using the forbidden word 'heat'. It is noticeable that, in the past 10 years or so, many textbooks have begun using the term 'thermal energy'. Unfortunately they rarely explain exactly what they mean by it – in particular, whether it is a synonym for 'heat' or for another well-defined (but different) scientific term 'internal energy'. In these notes, 'thermal energy' is a synonym for 'internal energy'.

To understand the issues involved here, we need to think a bit harder about what we mean by 'heat'. In everyday language, heat is something which hot objects possess. If heat is added to an object, its temperature rises – and if it loses heat, its temperature falls. If two objects at different temperatures are placed in contact, then heat will spontaneously flow from the hotter one to the cooler one – and will continue flowing until both are at the same temperature. For young pupils, these ideas are not trivial. Many require some time to separate the two ideas of heat and temperature.

The account above summarises the understanding of heat and temperature of scientists from around 1750, when Joseph Black first separated the ideas of heat and temperature, until around 1840, when Joule and others began to sort out the relationships between work, heat and energy. It is really a potted version of the *caloric theory of heat*. In this theory, heat is a quasi-material substance, which can flow from one place or object to another. The total amount of heat remains the same. This breaks down, however, when we think about situations where something has its temperature raised by rubbing it (due to friction). This seems to generate unlimited amounts of heat, which were not previously present – destroying the notion of heat as a conserved quantity.

Examples like this led scientists to develop a more complete model of thermal processes in which the *internal energy* of an object can be raised in two ways: by doing work on it (e.g. by friction), or by placing it in contact with another object at a higher temperature. The change of internal energy is the sum of the amount of work done on the object and the amount of heat transferred to it.

So it is not correct to say that:

Heat is a form of energy that is stored in hot objects. The higher the temperature of an object, the more heat it contains.

This is a definition of 'internal energy', or, 'thermal energy'.

A better definition of heat is:

Heat is energy that is transferred spontaneously from an object at a higher temperature to one at a lower temperature.

Some people have argued, however, that it is unnecessary to introduce the term 'heat' for this at all, and easier (and clearer) simply to talk about energy being transferred due to a difference in temperature – which we call the process of 'heating'. Bringing in the idea of heat is, they argue, an unnecessarily complication. For instance, it

involves reasoning about the interaction between a hot object and a cold one as follows:

internal energy in the hot object becomes heat which then becomes internal energy in the cold object

Instead they suggest simply saying:

energy is transferred from the hot body to the cold body; this process is called heating.

It is difficult, however, to sustain this precision of language when talking to pupils about objects getting hotter and colder – and it is necessary to build on their everyday knowledge. So the word ‘heat’ is likely to come into the conversation. A reasonable aim, therefore, of an introductory unit on thermal processes is to develop an understanding similar to *the caloric theory of heat* – clearly separating the ideas of ‘temperature’ and ‘heat’. Then, when teaching energy ideas, as discussed in section 8 above, the term ‘thermal energy’ might be introduced – probably appearing to most pupils to be a synonym for ‘heat’¹⁵. At a later stage, perhaps in Key Stage 4 but more probably at post-16 stage, the need for a more precise understanding of these ideas can be pointed out – and the difference between ‘heat’ and ‘thermal energy’ (or internal energy) made clear.

¹⁵ Indeed there is an argument for not introducing the term ‘thermal energy’ at all, but simply referring to this form of energy as ‘heat’.

References

- Boohan, R. and Ogborn, J. (1996a). *Energy and Change. Introducing a new approach. Activities for the classroom. Background stories for teachers.* Hatfield: Association for Science Education.
- Boohan, R. and Ogborn, J. (1996b). Differences, energy and change: a simple approach through pictures. *School Science Review*, 78, (283), 13-20.
- Driver, R., Squires, A., Rushworth, P., and Wood-Robinson, V. (1994). *Making Sense of Secondary Science*, chapter 20. London: Routledge.
- Duit, R. (1987). Should energy be introduced as something quasi-material? *International Journal of Science Education*, 9, 139-145.
- Ellse, M. (1988). Transferring not transforming energy. *School Science Review*, 69 (248), 427-437.
- Feynman, R. (1963). *The Feynman Lectures on Physics*. Book 1. New York: Addison-Wesley.
- Heath, N.E. (1974). Heating. *Physics Education*, 9, 490-491.
- Heath, N.E. (1976). Heating. *Physics Education*, 11, 389.
- Kaper, W. and Goedhart, M. (2002). 'Forms of energy', an intermediary language on the road to thermodynamics? Part I. *International Journal of Science Education*, 24 (1), 81-96.
- Kaper, W. and Goedhart, M. (2002). 'Forms of energy', an intermediary language on the road to thermodynamics? Part II. *International Journal of Science Education*, 24 (2), 119-138.
- Mak, S-Y. and Young, K. (1987). Misconceptions in the teaching of heat, *School Science Review*, 68 (244), 464-470.
- Ogborn, J. (1976). Dialogues concerning two old sciences. *Physics Education*, 11, 272-276.
- Ogborn, J. (1986). Energy and fuel - the meaning of the 'go' of things. *School Science Review*, 68 (242), 30-35.
- Ogborn, J. (1990). Energy, change, difference and danger. *School Science Review*, 72 (259), 81-85.
- Ross, K. (1988). Matter scatter and energy anarchy. The second law of thermodynamics is simply common experience. *School Science Review*, 69 (248), 438-445.
- Ross, K. (1993). There is no energy in food and fuels - but they do have fuel value. *School Science Review*, 75 (271), 39-47.
- Solomon, J. (1982). How children learn about energy, or Does the first law come first? *School Science Review*, 63 (224), 415-422.
- Summers, M. (1982). Teaching heat - an analysis of misconceptions. *School Science Review*, 64 (229), 670-676.
- Warren, J.W. (1972). The teaching of the concept of heat. *Physics Education*, 7, 41-44.
- Warren, J.W. (1976). Teaching thermodynamics. *Physics Education*, 11, 388-389.
- Warren, J.W. (1982). The nature of energy. *European Journal of Science Education*, 4 (3), 295-297.
- Warren, J.W. (1991). The teaching of energy. *Physics Education*, 26 (1), 8-9.

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